The Navigation Economic Technologies Program

July 31, 2005

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PATTERNS IN GEOGRAPHIC ELASTICITY ESTIMATES OF BARGE DEMAND ON THE UPPER MISSISSIPPI AND ILLINOIS RIVERS

US Army Corps of Engineers®

IWR Report 05-NETS-P-03

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

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PATTERNS IN GEOGRAPHIC ELASTICITY ESTIMATES OF BARGE DEMAND ON THE UPPER MISSISSIPPI AND ILLINOIS RIVERS

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WORD COUNT: 2 Tables + 9 Figures + Words = 500 + 2,250 + 3,240 = 6794 words.

ABSTRACT: This paper investigates patterns in the demand for barge transportation along the inland waterway system. Non-parametric techniques including both rolling regression and locally weighted regressions are used to visually analyze the pattern of elasticity estimates along the river at the pool level. The results of these non-parametric approaches visually indicate that barge demand elasticity may be more elastic on both the southern and northern reaches of the river, while being more inelastic toward the center of the waterway system. Based on the non-parametric analysis, higher order elasticity terms are used to parametrically investigate the pattern of elasticity along the inland waterway system. Using the parametric approach, the same patterns of elasticity arise wherein demands are relatively more elastic on the northern and southern ends of the waterway system and relatively less elastic in the center.

INTRODUCTION

Transportation demand models and their empirical estimation have long been important from both an academic and a policy perspective. Of particular importance has been the estimation of transportation demand elasticity. Numerous studies have estimated this elasticity for various modes of public transportation including: automobile usage where the estimated elasticity is between .01 and 1.26, urban transit with an estimated elasticity between .01 and 1.32, airline travel with an estimated elasticity between .36 and 4.60, and rail travel with an estimated elasticity between .12 and 1.54 (1). Equally important has been the estimation of freight transportation, i.e. the movement of commodities. The elasticity estimates of these various modes are found to depend heavily upon the commodity being transported but with general elasticity estimates of: rail transportation with an estimated elasticity between .02 and 3.50 and motor carrier transportation with an estimated elasticity between .14 and 2.96 (1).

Recently, these models have been of particular importance to navigation planning practitioners who model barge demand in conducting their welfare analysis of navigation improvements. In particular, the Tow Cost (TCM) and the Ohio River Navigation Investment Model (ORNIM) models assume that barge demand is constant up to the least cost alternative transportation rate at which point all traffic switches from barge to the alternative mode. Alternatively, the ESSENCE model assumes that demand is not constant, but rather falls as the barge price increases until the same threshold point is reached at which point all traffic again switches from barge to the alternative mode.

With respect to barge transportation there have been numerous recently studies attempting to estimate the demand elasticity of barge transportation. Yu and Fuller estimate that barge demand for grain is inelastic with estimates between -.50 for the Mississippi River and -.20 for the Illinois River (2). Dager, Bray, Murphree and Leibrock meanwhile estimate the demand elasticity of barge demand for corn shipments to be between -.7 and -.3, again both inelastic (3). Train and Wilson use both revealed and stated preference data to analyze both mode and origin-destination changes as a result of an increase in the barge rate. Using this framework they estimate barge demand elasticities between -.7 and -1.4 (4).

Henrickson & Wilson estimate barge demand elasticity by explicitly controlling for the spatial characteristics of each grain elevators transportation decision (5). In doing this they find elasticity estimates between -1.41 and -1.90 which are much larger than the results found by Dager et al. (3) and Yu and Fuller (1), but similar to those found by Train and Wilson (4).

While Henrickson and Wilson do explicitly account for spatial characteristics affected grain elevators, they also implicitly make the assumption that barge demand elasticity is constant across the river. There are two main arguments for a non-constant elasticity across the river. First consider shippers located at the southern end of the Upper Mississippi River. Theoretically, is these shippers could be more responsive to changes in the barge rates because they have a shorter distance to the destination and could bypass the river by using more expensive alternative modes of transportation if the barge rate increased. Alternatively, shippers located at the northern end of the Upper Mississippi River may also be more responsive to changes in the barge rate because they have the longest distance to the downriver destination. These shippers may find it worthwhile to ship to an alternative destination (e.g. the Pacific Northwest) via a more costly mode if the barge rates increased.

In this paper an attempt is made to describe the effects of relaxing this assumption by allowing the estimated barge elasticity to vary along the river. Non-parametric approaches, both rolling regressions and locally weighted regressions, are used to estimate the approximate pattern of demand elasticity along the river. Using these results, we then use parametric approaches to estimating the barge elasticity along the river. Both our non-parametric and parametric results support the hypothesis that barge demands are relatively more elastic on the northern and southern ends of the river and relatively inelastic towards the center of the waterway system.

Section 2 provides a more complete background of the previous literature analyzing barge transportation demand. Section 3 presents the empirical strategies used to estimate geographically varying elasticity estimates. Section 4, outlines the data used for the analysis. Section 5 presents the results of our various geographically varying elasticity estimation techniques, while in Section 6 provides concluding comments.

BACKGROUND

Yu and Fuller estimate six separate grain barge demand equations for each of the Mississippi and Illinois Waterways. They find that the demand elasticity for barge transportation on the Mississippi River is approximately -.50 and on the Illinois River is about -.20. However, as they acknowledge themselves “The models estimated yield weak statistical results” (2). Indeed, many of their theoretically important variables are not statistically significant and reverse signs across their various specifications.

Dager et al. regress the tons of corn barged by month and by river section on the monthly price of corn in New Orleans less a proxy for local price less the monthly corn tariff, foreign grain demand, monthly or seasonal dummy variables, and the number of empty barges. Using this strategy they estimate the elasticity of barge demand for corn to be between -.7 and -.3 (3). Dager at al. also attempt to control for geographically varying elasticity estimates by estimating this equation for four separate sections of the river. However, it is unclear whether the four sections of river they chose appropriately segment of the river.

Train and Wilson use survey data and both stated and revealed data to analyze the effects of changes in both barge rates and barge transportation times on mode choices and origin-destination choices. They find that many shippers respond to even a small change in the current barge rate by changing either their mode of choice or their origin-destination choice. Further, they find that shippers are also responsive to barge transit time, but less so than to changes in the barge rate (4).

Henrickson and Wilson develop a theoretical model of barge demand from the perspective of port grain elevators. In this model, they are able to account for the spatial competition between these elevators. Using this model they estimate the responsiveness of port grain elevators located along the Mississippi and Illinois Rivers to barge rates in order to estimate barge demand elasticities. Using both OLS and pool specific fixed effects, they estimate barge demand elasticites of -1.4 to -1.9. However, as stated previously, they assume that these elasticity estimates apply to the whole length of the river, i.e. they assume a constant elasticity (5).

EMPIRICAL MODELS

Henrickson and Wilson develop a theoretical framework whereby grain elevators choose their bid price, and subsequently their quantity, so as to maximize their profits (5). The profit maximizing quantity is found to be a function of the price at the destination, the transportation rate, service induced costs, and procurement/processing costs determinants:

$$Q^*_{md} = Q^*_{md}(P_d, t_{md}, s_{md}, c, D, y)$$

Using this equation, Henrickson and Wilson then develop an empirical model where quantity shipped is regressed on: the barge rate, the rate from farmers to the elevator's location, the alternative mode rate, firm capacity, the distance to the nearest competitor, the number of firms in the area, the capacity of the firms in the area, area production, origin mile, and a dummy variable to denote elevators owned by large conglomerate firms.

In this study, we use the same empirical model as Henrickson and Wilson, but we relax the assumption of constant elasticity to examine whether barge demand elasticity varies across the river.

To examine the pattern of barge demand elasticity along the river, two non-parametric techniques: rolling regressions and locally weighted regressions are used to describe the patterns of estimates. In each of these non-parametric models, the data are ordered in ascending order according to river mile. The estimation equation developed by Henrickson and Wilson is then run on subsets of the data, the difference between the rolling regressions model and the locally weighted regressions model being how the subset is used in the estimation process.

In the rolling regressions model, the estimation equation, as specified above, is run on a "window" of data. The size of the window is arbitrary, and thus various specifications of the window size are run. Essentially, the barge demand equation is run on the first x observations and the demand elasticity is recorded (the first x observations correspond to the x shippers located furthest south, x is our window size). Note that x is arbitrarily chosen, and the only restriction on it is that it must be large enough to estimate the equation. The barge demand equation is then run on observations 2 through x+1 and the demand elasticity of this equation is then recorded. The equation is then run on 3 through x+2, 4 through x+3, etc. In essence, we are taking a window of size x and moving it along the river one position at a time estimating the demand elasticity in each window location.

The second non-parametric technique used to examine elasticity over space is a locally weighted regression developed by Cleveland (6). This technique is similar to the rolling window technique with one notable difference. Again, one must specify a window size in which the demand equation will be run and again move the window up the river one position at a time. The key difference is that the observations in the window are weighted such that the middle position gets the highest weight and each position away from the middle gets subsequently lower weights. For example, if a window size of 5 was specified, the middle position would be the 3rd observation in the window and it would receive a weight of 1, indicating that it is fully weighted. Positions 2 and 4 would receive a weight of .89 each, positions 1 and 5 would receive a weight of .35 each, and positions 0 and 6 would receive a weight of 0 meaning that they are not included in the regression. Note that this weighting scheme is the tricube weight proposed by Cleveland (6). Weighted least squares is then used to estimate the demand elasticity for the given middle location and window size. The estimated elasticity is then recorded and the window is moved up the river one location and estimated again.

To further examine the patterns of barge demand elasticity along the river, we estimate different parametric specifications of the Henrickson and Wilson empirical model (5). In particular, interactions between barge rates and different polynomials up to three powers are used in an attempt to capture the relevant patterns.

DATA

The majority of data used for this analysis came from the Tennessee Valley Authority (TVA). The TVA collected these data during two sets of personal interviews of barge terminals located along America's inland waterways. According to the U.S. Army Corps of Engineers' Port Series database, there are currently almost 200 elevators located along the Mississippi and Illinois Rivers whose stated purpose is the shipment of grain. These elevators can be seen in Figure 1.

For this study, we use the same subset of data as Henrickson and Wilson (5). In particular, we analyze the 103 grain elevators located on the Upper Mississippi and Illinois rivers as shown in Figure 2. Note that we matched the TVA data with the USACE Port Series to obtain these terminal locations.

During the course of their interviews, the TVA collected information regarding each location's annual tons shipped, commodities shipped, barge charges, truck transfer charges, the termination of the shipments, their average gathering area of product to be shipped, and alternative routes that they could have sent that shipment if not by barge.

These data are supplemented with crop yields per acre and harvest levels at the county level from USDA.

Variables

The variables included in our empirical model come directly from Henrickson and Wilson (5). Our dependent variable is the *barge rate* which is defined as the rate per ton-mile of the barge movement. Our independent variables include: the *transportation rate from the farmer to the elevator* which is defined as the rate per ton-mile of using truck or rail to transport the commodity to the river terminal facility (i.e., in the context of the model developed by Henrickson and Wilson, it is the farmer's transportation cost); the *alternative rate* is the rate per ton-mile of the most common alternative to shipping down the river; *distance to nearest competitor* is the distance to the nearest competitor; *capacity* is the capacity in bushels of the elevator; *number of firms in area* in the number of competing elevators on the same bank of the same pool (pool being defined as the area between any two locks); *capacity of firms in area* is the capacity of the other firms in the same pool on the same bank; *area production* is the average production of the commodity in the county and bordering counties; and the *dummy variable for large conglomerate firms* is a dummy variable equal to 1 if the shipper is one of the six conglomerate firms in our sample. Summary statistics of each of these variables are provided in Table 1.

These statistics suggest there is considerable variation in annual ton-miles shipped. That barge rates per ton-mile are, as expected, much smaller than alternatives (rail and truck). Rates inbound to the shipping elevator are approximately 7 time higher than the barge rates, but much less than the alternative rate, owing to shorter distances. Firm capacity and area capacity vary quite a bit from elevator to elevator. The distance between elevators is about 1.75-6.5 miles, while the number of firms in the same area appears to be approximately 4. There also appears to be considerable variation in the area production of crops. Finally, the gathering area (the distance of inbound shipments) has a median value of 60 miles and an average value of about 68.3. Further, a simple regression of gathering area and river mile indicates that gathering areas increase with river mile, and a 100 mile increase in river mile increases gathering areas about 4 miles. From the lower reaches of the river to the most northern areas, this suggests a difference in gathering area of about 33 miles.

RESULTS

Rolling Regressions

We run the rolling regressions technique over 3 different window sizes (x): 30, 40 and 50. Figures 3, 4 and 5 show the results of using the rolling regressions model with each of these window size specifications. Notice that as the window size increases, the "bumpiness" of the graph decreases. This is because as we add more observations to each individual regression in the rolling regression technique we approach the estimates obtained when running the estimation equation on the total sample.

Inspecting Figures 3, 4 and 5 it appears that elasticity is more inelastic the further up the river an elevator is located. However, there also appears to be a pattern consistent with the elasticity being most inelastic in the center of our range and more elastic towards the top and bottom of the range that coincides with previous explanation of why elasticity may not be constant. That is, elevators located at the northern end of the river may be more responsive to barge rate changes because they have the longest distance down river and therefore may choose to ship to an alternative market such as the northwest; while elevators located on the lower portion of the river may choose to bypass the river and use rail instead given their shorter distance to their destination.

Locally Weighted Regressions

We run the locally weighted regressions technique over 3 different widow sizes (x) as well: 40, 60, and 80. We use larger window sizes with the locally weighted regressions technique than we did with the rolling regressions because observations are weighted less as one moves away from the center observation therefore we can use more information (more observations) without losing the ability to visually gain information regarding what is happening at the center of the specified window. Figures 6, 7 and 8 show the results of using the locally weighted regression model with each of these window size specifications. Again, notice that as the window size increases, the "bumpiness" of the graph decreases. Also notice that Figures 6, 7 and 8 are much smoother than Figures 3, 4 and 5 due to its larger sample size.

Visually, Figures 6, 7 and 8 seem to show more elastic barge demand along the southern and northern parts of the river with less elastic demand in the center. As with the results of the rolling regression model, this conforms to our previous story and indicates that the pattern of barge demand elasticity is one where demand is inelastic in the middle of the waterway system and more elastic towards the upper and lower ends of the system.

Parametric Specifications of Elasticity Along the River

The results of various specifications of elasticity estimates based on the non-parametric pattern of Figures 3 through 8 are presented in Table 2 and in Figure 5.

Figure 5 graphically shows the estimates of each of our varying coefficient models. These results indicate that shippers located along the southern section of the waterway system appear to be more responsive to changes in the barge rate, while shippers located further up the river appear to be less responsive. The cubic model which allows for a second switch in the elasticity trend indicates that the elevators located at the extreme north end of the river do tend to be more elastic than their counterparts located towards the center of the river.

Using both non-parametric and parametric techniques we have developed a consistent picture with regard to the pattern of barge demand elasticity along the Upper Mississippi and Illinois Rivers. Each of our specifications indicates that barge demand is more elastic for grain elevators located on the northern and southern ends of the river while barge demand is more inelastic for elevators located towards the center of the waterway system. This finding is consistent with the idea that elevators located towards the middle of the waterway system have fewer options (than elevators located at the northern and southern ends of the waterway system) with regard to both where and how they ship their commodities.

CONCLUSION

This paper expands upon the Henrickson and Wilson (5) framework investigating the pattern of barge transportation demand elasticity along the inland waterway system. We first use the non-parametric techniques or rolling regressions and locally weighted regressions to visually analyze the pattern of elasticity estimates along the river. We then use higher order elasticity terms to parametrically examine the pattern of barge demand elasticity. Both our non-parametric and parametric approaches indicate the presence of the same pattern of barge demand elasticity along the Upper Mississippi and Illinois River. That is that barge demand is more elastic for elevators located on both the northern and southern ends of the waterway system while demand is more inelastic for elevators located towards the center of the waterway system. Furthermore, this pattern is consistent with the idea that elevators located towards the center of the waterway system have less options with regard to where and how to ship their commodities. One possibility for future research, which we are perusing, is to extend the dummy variable approach of both Yu and Fuller (2) and Dager et al. (3) by endogonizing the choice of dummy variables using the method developed by Hansen (7) and allow the data to determine what dummy variables should be specified, and use this model to estimate barge demand elasticities along the Upper Mississippi and Illinois Rivers.

ACKNOWLEDGEMENTS

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LIST OF TABLES AND FIGURES

TABLE 1 Descriptive Statistics

Variable	Centile	Average
Annual Ton-Miles (thousand)	13,900	56,900
Barge Rate	.012	.011
Transportation Rate to Elevator	.089	.094
Alternative Rate	.128	.125
Firm Capacity (thousand)	574	1,850
Distance to Nearest Competitor	1.75	6.58
Area Capacity (thousand)	1,413	4,788
Number of Area Firms	4	4.1
Area Production (thousand)	41,600	58,400
Gathering Area	60	68.30

TABLE 2: Parametric Geographically Varying Elasticity Estimates

Model	Barge Rate Estimate	Barge Rate Interacted with River Mile Estimate	Barge Rate Interacted with River Mile Squared Estimate	Barge Rate Interacted with River Mile Cubed Estimate	Joint Significance of Elasticity	Joint Significance of Non-Constant Terms
Constant Elasticity	-1.90*** (.706)					
Linear Elasticity in River Mile	-2.54** (1.13)	.002 (.003)			F = 3.87**	F = .52
Quadratic Elasticity in River Mile	-1.65 (1.40)	-.005 (.007)	.00002 (.00002)		F = 2.97**	F = .84
Cubic Elasticity in River Mile	-1.73 (1.41)	-.01 (.01)	.00007 (.00006)	.00000007 (.00000008)	F = 2.42**	F = .82

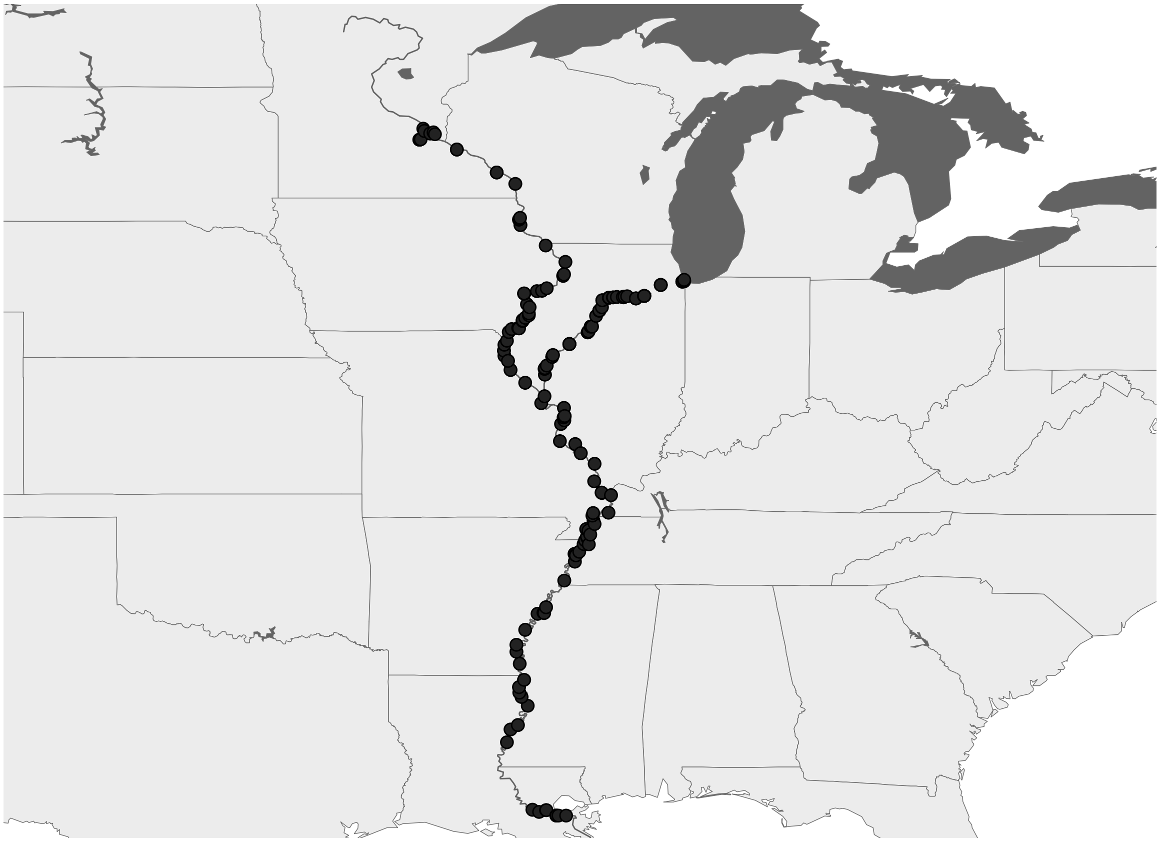

FIGURE 1 Barge Terminal Locations of Grain Shippers on the Mississippi and Illinois Rivers

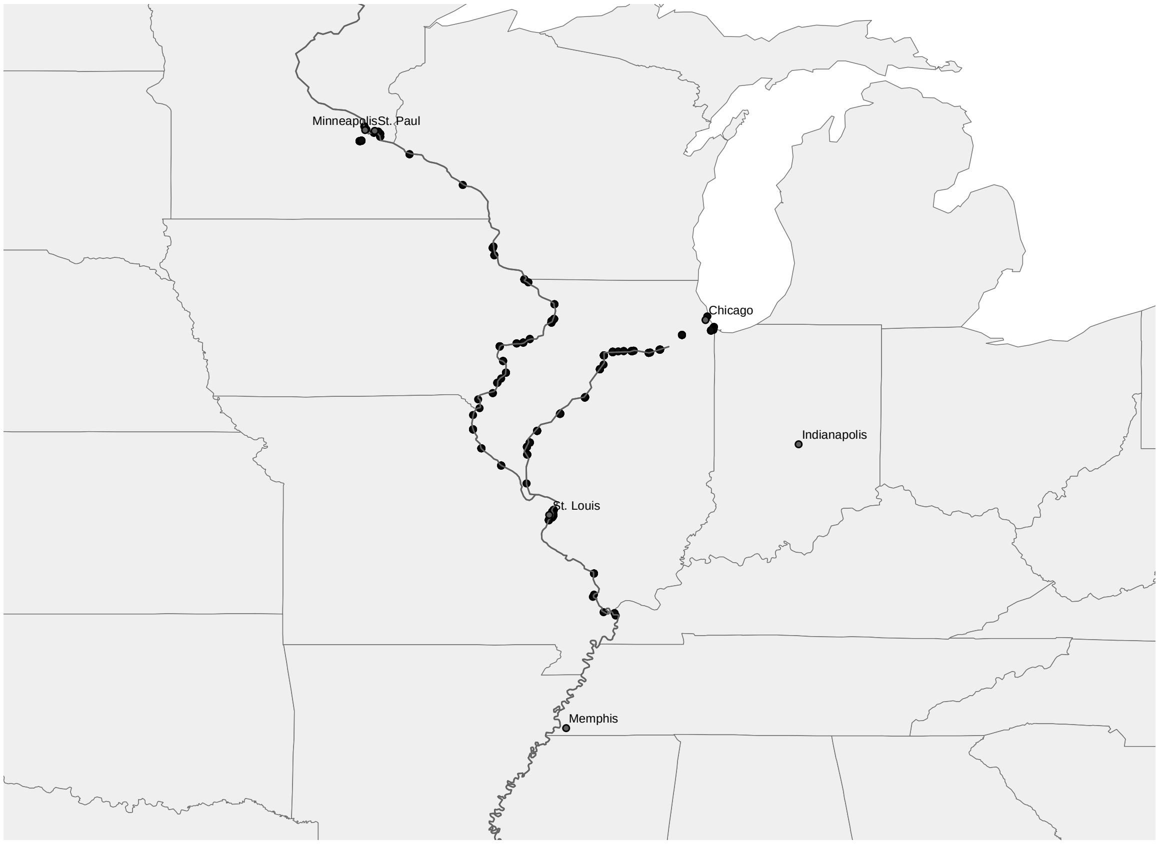

FIGURE 2 Barge Terminal Locations Shipping Grain From TVA Survey

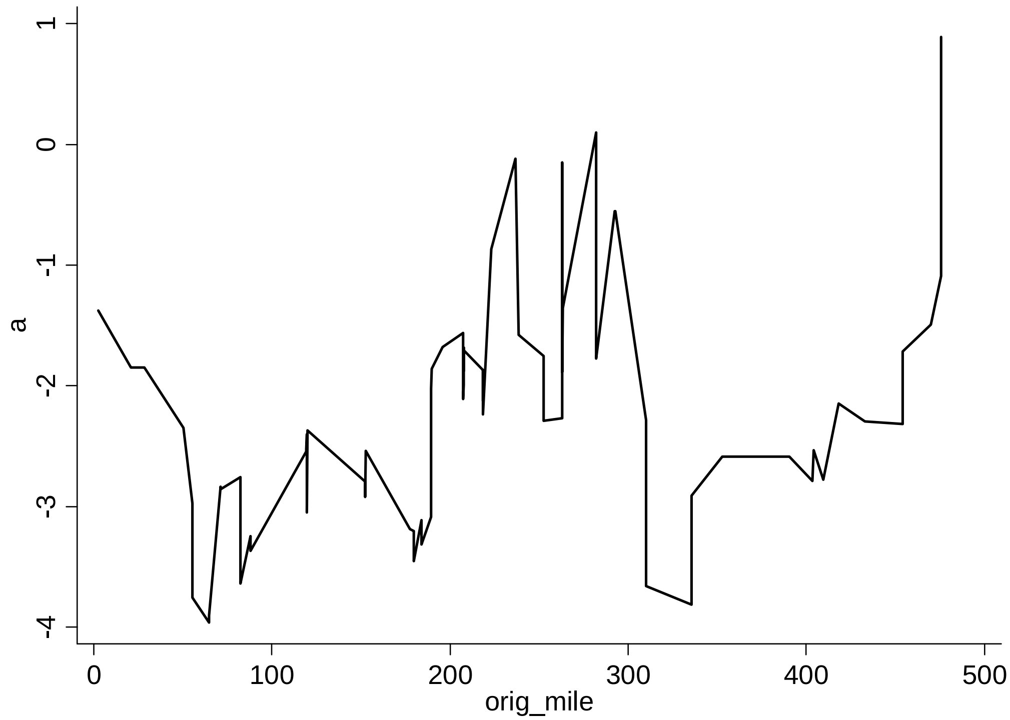

FIGURE 3: Rolling Regressions Estimates with Window Size 30

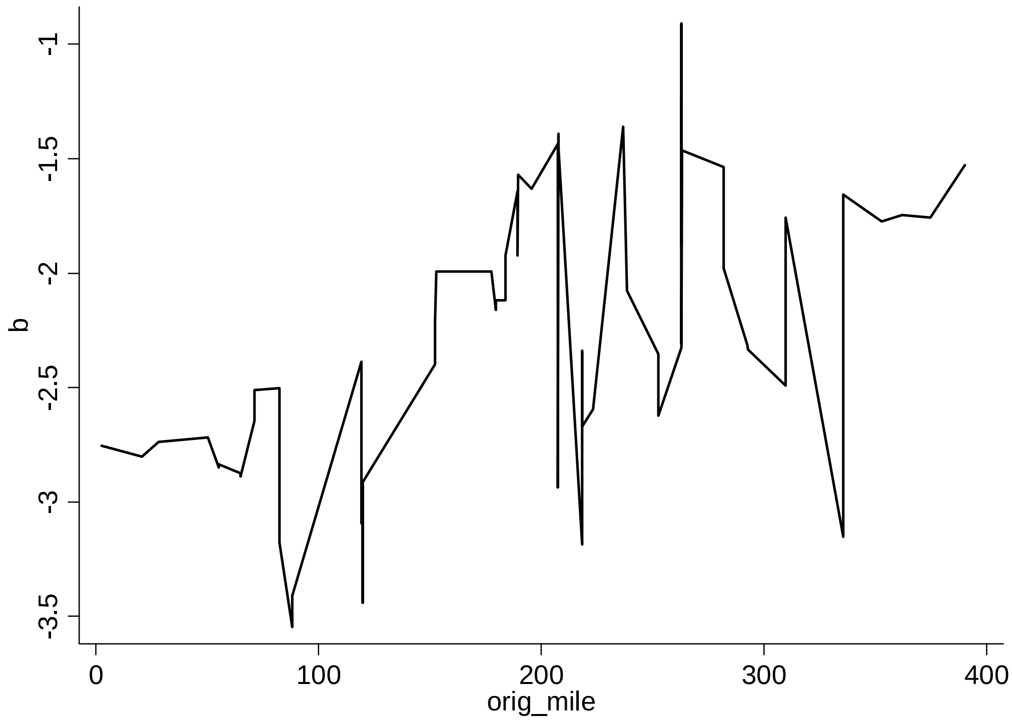

FIGURE 4: Rolling Regressions Estimates with Window Size 40

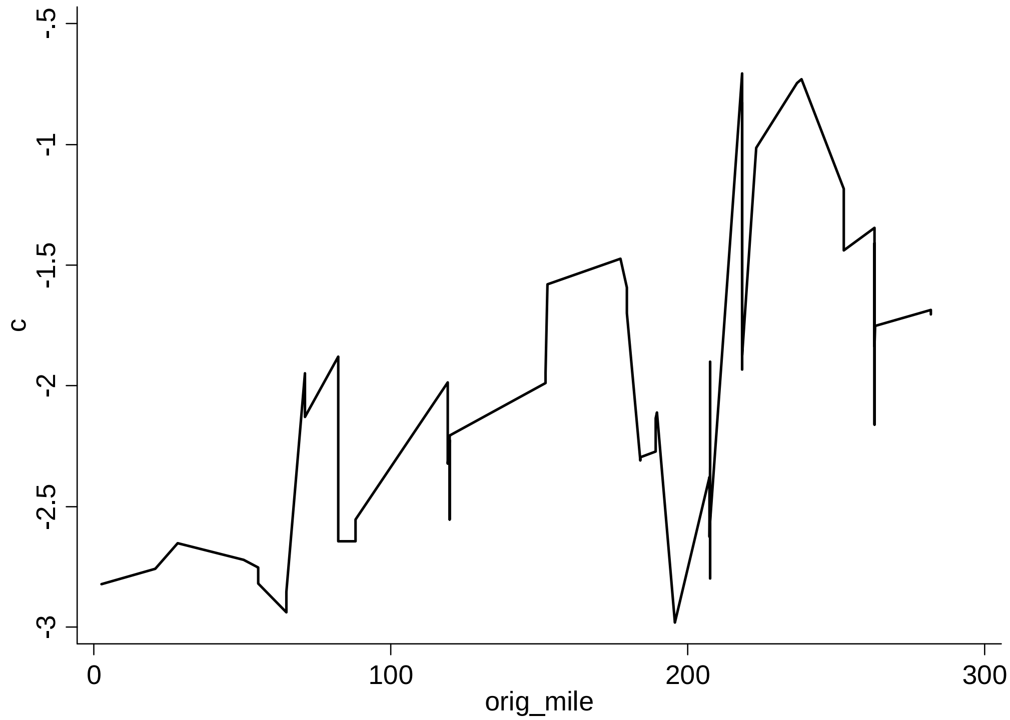

FIGURE 5: Rolling Regressions Estimates with Window Size 50

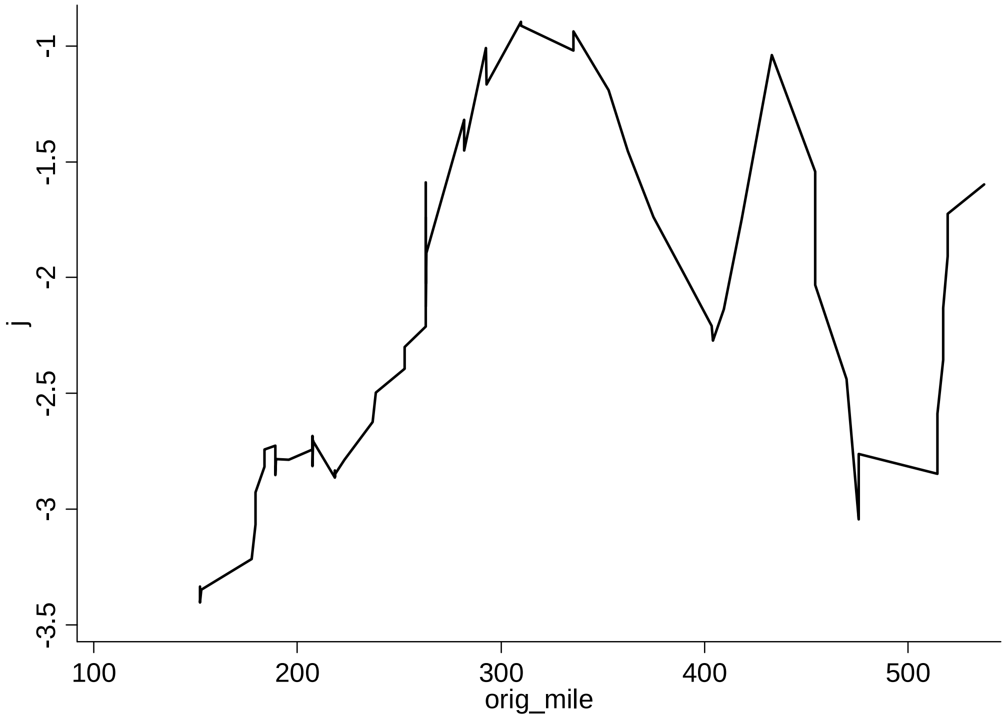

FIGURE 6: Locally Weighted Regressions Estimates with Window Size 40

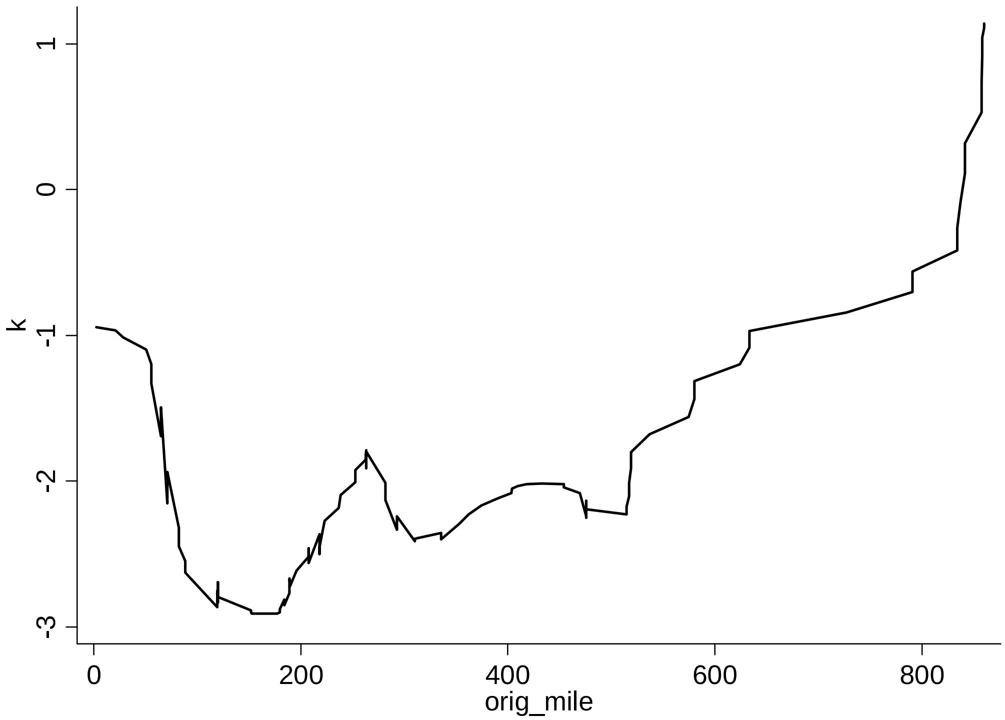

FIGURE 7: Locally Weighted Regressions Estimates with Window Size 60

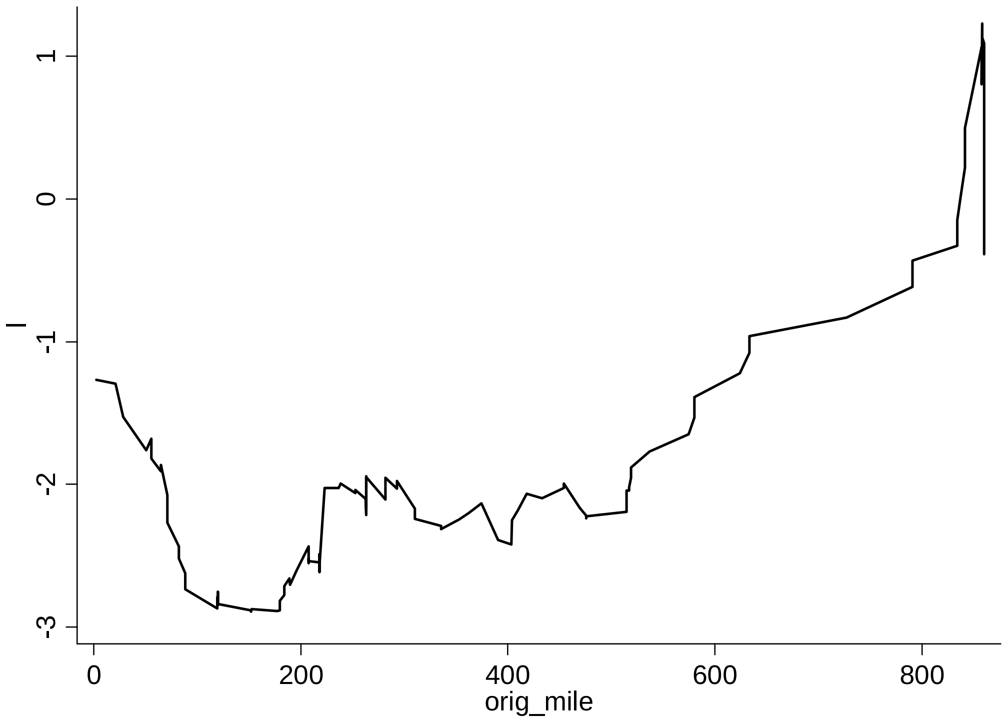

FIGURE 8: Locally Weighted Regressions Estimates with Window Size 80

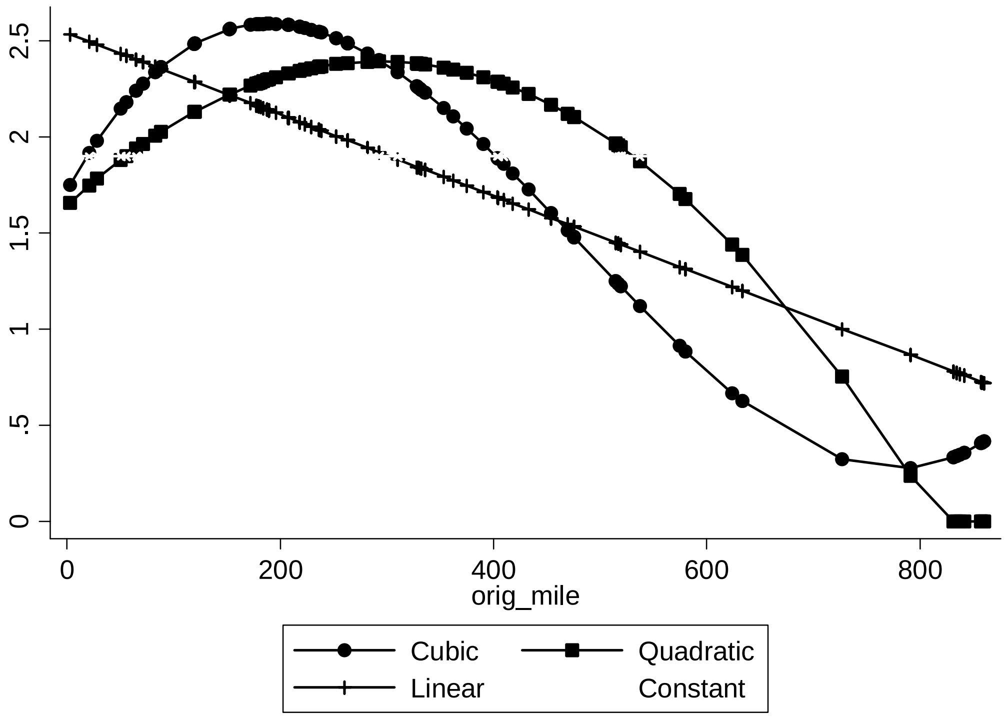

FIGURE 9: Parametric Geographically Varying Elasticity Estimates

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The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting international and domestic traffic flows and how they may be affected by project improvements.
- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

As these models and other tools are finalized they will be available on the NETS web site:

http://www.corpsnets.us/toolbox.cfm

The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

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